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Determinants of the benefit for consistent spatial mappings in dual-task performance of three-choice tasks

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Performance of pairs of three-choice tasks shows a consistency benefit for which reaction times are shorter when the stimulus–response mappings for each task are consistent (both corresponding or both mirrored) than when they are inconsistent. In the present study, we examined whether this consistency benefit is reduced at long stimulus onset asynchronies, as it is for pairs of two-choice tasks, or is relatively unaffected, as it is for pairs of four-choice tasks. The consistency benefit was evident for both corresponding and mirrored mappings, at all intervals. For consistent mirrored mappings, the benefit was found for the side stimulus positions (for which responses are crossed) but not for the center position, whereas for consistent corresponding mappings, a benefit was evident for the center position as well. The results for both mappings are in agreement with an emergent mapping-choice account. The consistent corresponding mapping also benefits from subjects' ability to apply a respond-corresponding rule across tasks. An emergent perceptual-feature process that contributes to the consistency benefit for two-choice tasks does not seem to play a role in tasks with three or more choices.

When people must react to two stimuli from different tasks presented in close temporal proximity, the relation between the tasks can influence performance. For example, it is easier to perform the tasks when the stimulus and response modalities differ than when they are the same (e.g., Lien & Proctor, 2000). Also, when response sets for the tasks are similar (e.g., index- and middle-finger keypresses with the left hand for one task and with the right hand for the other), response–response (R–R) compatibility effects occur in which performance is better when the stimuli for both tasks signal spatially corresponding responses rather than noncorresponding responses (e.g., Hazeltine, 2005). Another factor, of most concern here, is consistency of the stimulus–response (S–R) mappings for the two tasks: Performance is better when the mappings for the two tasks are the same (both corresponding or both mirror opposite) than when they are different.

This consistency benefit has been obtained for pairs of two-, three-, and four-choice tasks, with the former showing an interaction of the benefit with stimulus onset asynchrony (SOA) that implicates an emergent perceptual-feature account (Vu & Proctor, 2006) and the latter an absence of interaction that implicates an emergent mapping-choice account (Proctor & Vu, 2009). Existing data for three-choice tasks obtained by Duncan (1979) are ambiguous regarding the presence or absence of an interaction, because his longest SOA was less than half that used in other studies. Moreover, three-choice tasks have the unique characteristic that the response for the middle stimulus position is the corresponding middle response position, regardless of whether the task mapping is corresponding or mirror opposite. For this reason, Duncan (1979) reported data only for the side-position responses. However, the middle-position responses should also be informative about the influence of mapping consistency on response selection, because any differences between consistent and inconsistent mappings cannot be attributed to the local level of the individual S–R pairings. Therefore, in the present study, we provide a detailed examination of the consistency benefit in three-choice tasks with a wider range of SOAs and for both middle and side locations.

Consistency Benefit With Three-Choice Tasks

Duncan (1979) was the first to show the mapping consistency benefit, using pairs of three-choice reaction tasks in a psychological refractory period (PRP) paradigm, in which the onset of the stimulus for Task 1 (S1) preceded that for Task 2 (S2) by a variable SOA of 50, 250, or 450 msec. For Task 1, the stimuli were vertical lines presented in one of three locations to the left of fixation, each assigned to a keypress response (R1) from the ring, middle, or index finger of the left hand. For Task 2, the

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stimuli were vertical lines presented in one of three locations to the right of fixation, each assigned to a keypress response (R2) from the same fingers of the right hand. The mapping for each task was *corresponding* (the key corresponding to the stimulus location was to be pressed) or *mirrored* (the key at the mirror-opposite location was to be pressed). In different trial blocks, all combinations of mappings for each task were used. Thus, the mappings for the two tasks were *consistent* when they were both corresponding or both mirrored and *inconsistent* when one mapping was corresponding and the other mirrored.

For the side responses (those made by the index and ring fingers on each hand) examined by Duncan (1979), reaction times (RTs) for Task 1 (RT1) and Task 2 (RT2) were shorter when the mappings were consistent than when they were not. Most surprising, for both Task 1 and Task 2, RTs for the mirrored mapping were shorter when the mapping with which it was paired was also mirrored than when it was corresponding. Duncan (1979) interpreted the mapping consistency benefit in the following manner: "When the two mappings differed, there was always some uncertainty over which to use. In other words, an element of choice between *mappings* was emergent" (p. 220). He made clear that this emergent mapping choice was present for selection of both R1 and R2. Duncan's (1979) point was that when the mappings are consistent, only one mapping must be maintained in working memory as part of the task set, and there is no uncertainty about which mapping to apply to a given stimulus. In contrast, "especial difficulties arise when stimulus–response mappings are different for first and second reactions. It appears that for each reaction there is some (emergent) uncertainty over which mapping to use" (p. 216). This uncertainty arises because both mappings must be maintained in the task set and the appropriate mapping chosen before it can be applied.

In agreement with the supposition that mapping choice is a component process of performance with inconsistent mappings, regardless of the SOA, Duncan's (1979) results showed no significant interaction of consistency with SOA for RT1 and only a slight interaction for RT2, which he dismissed as "small and without obvious theoretical interest" (p. 223). As additional support for the emergent mapping-choice account, Duncan (1979) reported an analysis of incorrect responses for the inconsistent mapping conditions, which showed that an error was most often the response that would be correct if the wrong mapping rule were chosen and applied.

Consistency Benefit With Two- and Four-Choice Tasks

The mapping consistency benefit has also been shown to occur for pairs of four-choice and two-choice tasks, in which the task mapping differentiates responses for all stimulus positions. Proctor and Vu (2009) showed that consistent mirrored mappings of four stimulus locations to four keypresses yielded a benefit relative to situations in which the mapping was mirrored for one task and corresponding for the other. They extended the range of SOAs to 1,000 msec and still found little reduction in the consistency benefit. The finding that the consistency benefit remained evident at SOAs as long as 1,000 msec is in agreement with Duncan's (1979) emergent mapping-choice account and suggests that it is applicable to performance of four-choice tasks.

In contrast, the two studies of consistency benefits for pairs of two-choice tasks showed interactions such that the benefit decreased as SOA increased and was absent for consistent mirrored mappings at the 1,000-msec SOA (Ivry, Franz, Kingstone, & Johnston; 1998; Vu & Proctor, 2006). Because the results are discrepant with the prediction of the emergent mapping-choice account that the consistency benefit should be evident at all SOAs, Vu and Proctor (2006) attributed the benefit for two-choice tasks to correspondence of an emergent blank feature with the responses when both task mappings were mirrored. With mirrored mappings of two stimulus locations to two keypresses, at short SOAs the blank stimulus locations that contain no stimuli correspond to the locations of the correct responses (see Figure 1A). For example, if the stimuli for each task are in the left relative positions, the right unfilled locations correspond to the correct right responses that are to be made. This emergent perceptual blank feature is unavailable at long SOAs, because the two unfilled locations pop out as a separate perceptual grouping only when both stimuli are visibly present. Thus, a strategy of responding compatibly to the blank locations for both tasks would facilitate responding at short SOAs but not at longer ones. Vu and Proctor (2006) provided additional support for the emergent perceptual-feature account by showing that there was no benefit for consistent mirrored mappings at any SOA for pairs of two-choice tasks in which left and right tones were used as stimuli for Task 1, thus removing the emergent blank feature.

The Present Study

In the present experiment, we examined the basis of the consistency benefit using a three-choice task, which is intermediate to the two- and four-choice tasks just described. Although Duncan (1979) concluded that his results for three-choice tasks supported an emergent mapping-choice explanation, the results do not unequivocally rule out an emergent perceptual-feature account. Correspondence of the emergent blank feature with the responses, which occurs for all trials in two-choice tasks and for none in four-choice tasks, holds for a subset of trials in three-choice tasks (see Figure 1B). With consistent mirrored mappings, the correct response to a stimulus in a side position is compatible with the relative location of the blank area encompassing the two unoccupied locations. When both S1 and S2 appear in side positions, a relation of *respond compatible to the blank regions* exists similar to that for two-choice tasks. This relation does not hold, though, for any trial in which S1 or S2 occurs in a middle position. Because a strategy of responding compatibly to the blank areas is not applicable to the middle locations, it is less likely that subjects would use the emergent blank feature strategy for three-choice tasks. However, the strategy could be used if a decision were first made as to whether the stimuli are in middle or side positions.

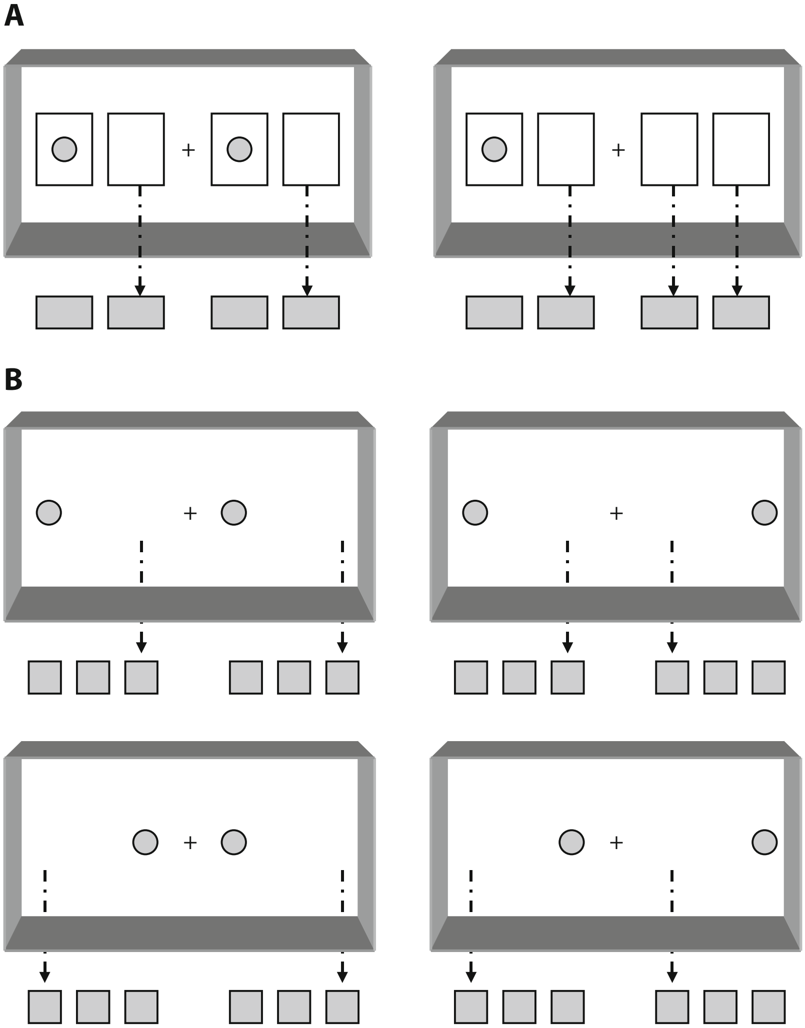

Figure 1. Illustration of the emergent perceptual feature of the consistent mirrored mapping conditions for the display in Vu and Proctor's (2006, Experiment 1A) two-choice task (A) and that in Duncan's (1979, Experiment 2) three-choice task (B). For panel A, the left side illustrates one combination of displays when S1 and S2 are visible at the same time, whereas the right side illustrates a display when S1 was visible by itself prior to onset of S2. The blank boxes correspond to the correct response locations when S1 and S2 are both visible but not when only S1 is visible. For panel B, all four possible S1–S2 pairings for the side locations analyzed by Duncan (1979) are shown. The locations of the blank areas relative to the targets correspond with the response location.

Though Duncan (1979) found little evidence in his three-choice tasks of the interaction of mapping consistency with SOA predicted by the emergent perceptual feature account, the power of his experiment for detecting such an interaction was relatively low. He tested only 8 subjects, compared with 16 in each of Vu and Proctor's (2006) experiments, and his longest SOA was 450 rather than 1,000 msec. For two-choice tasks with a left–right task distinction, Vu and Proctor (2006) found the consistency benefit to be still evident at a 400-msec SOA (166 msec for the Task 1 mirrored mapping as a function of whether the Task 2 mapping was mirrored or corresponding and 96 msec for the Task 2 mirrored mapping as a function of whether the Task 1 mapping was mirrored or corresponding), but the benefit was smaller than at a 50-msec SOA (280 and 256 msec for Tasks 1 and 2, respectively). Only at the 1,000-msec SOA was the benefit absent (5 and 14 msec, respectively). To increase the power of detecting a reduction of the consistency benefit with increasing SOA for three-choice tasks, in the present study we tested 16 subjects using SOAs ranging from 50 to 1,000 msec.

Whether two-choice tasks are performed differently from three- and four-choice tasks is an issue that extends beyond the mapping consistency paradigm. Shaffer (1967) remarked, "The change from a two-choice to a three-choice task is more than a trivial numerical extension. In a two-member set (A_1, A_2) the member not-A_i is uniquely defined logically, but this is not the case in larger sets" (p. 101). Shaffer (1966) found transition and cuing effects for three-choice tasks that differed markedly from those that he had previously obtained for two-choice tasks. One relevant finding was that repetition of the cue from the previous trial (a mapping repetition) was beneficial for three-choice tasks only when the imperative stimulus (and thus the response) also repeated but was beneficial for two-choice tasks even when the imperative stimulus (and response) changed. More recently, Wühr and Kunde (2008) reported that, for a Simon task in which stimulus location was irrelevant and color relevant, subjects benefited from cuing the spatial relation on the trial as noncorresponding for two-choice but not three-choice versions. In the present study, a lack of interaction of the consistency benefit with SOA would imply that the mechanisms underlying the benefits in three-choice tasks are like those in four-choice tasks but not those in two-choice tasks.

As was noted above, a unique aspect of three-choice tasks is that the middle position requires the corresponding response regardless of whether the task mapping is corresponding or mirror opposite. However, those responses should be informative regarding the nature of response selection, because the individual S–R pairing is consistent when the overall task mappings are inconsistent, and with consistent mirrored mappings, the middle position does not conform to a crossing rule that characterizes the outer positions. With mirrored mappings, people may adopt a strategy of determining whether the stimulus is in a side position or the middle position, and then applying a crossed rule only if the stimulus is in a side position. Moreover, when both S1 and S2 are determined to be in outer positions, with a consistent mirrored mapping, subjects could possibly benefit from responding compatibly to the emergent blank feature at short SOAs. Whether a middle–side strategy is employed can be evaluated by examining the errors that are made for side and middle positions. If the mirrored mapping is applied only after a side decision was made, no advantage for consistent mirrored mappings should occur at the middle position, because this middle versus side procedure is performed regardless of whether the task mappings are consistent.

Even if there is no consistency benefit at the middle position for the mirrored mapping, a consistency benefit may be evident for the corresponding mapping. When subjects perform only a single task on a given trial, but with the mapping unknown prior to onset of the imperative stimulus, there is a greater mixing cost for the compatible than for the incompatible mapping (e.g., Shaffer, 1965; Vu & Proctor, 2004). In other words, people respond relatively faster when all stimulus events require corresponding responses. Duncan's (1979) study showed evidence of a similar benefit when all S–R pairings were corresponding in the dual-task context, although he did not emphasize this point. His experiment included single-task conditions in which only Task 1 or Task 2 was performed with a mirrored or corresponding mapping. The benefit for the corresponding mapping was 52 msec for Task 1 alone compared with 120 msec in the dual-task context, and 83 msec for Task 2 alone compared with 140 msec in the dual-task context. This difference may be due to the subjects' being able to treat the consistent corresponding mappings as a single task in the dual-task context because a corresponding response rule was applicable to all positions, regardless of task. The mirrored mappings could not be treated similarly, because the mirror opposite rule applied within the three locations for a task and not across the six locations as a whole. If responses with consistent mirrored mappings are slowed by a requirement to apply the rule separately for each task, the advantage for the consistent corresponding condition relative to the consistent mirrored condition should be evident for the middle-position responses as well as for the side-position ones.

METHOD

Subjects

Sixteen students from Purdue University participated for credits toward an introductory psychology course requirement. All of the subjects had normal or corrected-to-normal vision.

Apparatus and Stimuli

The stimuli were presented on personal computers with 14-in. VGA color monitors. Micro Experimental Laboratory (MEL v 2.01) was used to program the experiment. The subjects sat in front of the monitor, at a distance of approximately 50 cm. A crosshair (0.5º × 0.5º) located in the center of the screen served as a fixation point. Three outline boxes (2.2 × 3.8 cm, 2.5º × 4.3º) were presented to the left of the fixation cross, and three to the right, to serve as placeholders for possible stimulus locations (see Figure 2). The boundaries of the boxes were separated by 1.8 cm. The three boxes for Task 1 were outlined in green and the three boxes for Task 2 in red. The imperative stimulus was a solid white circle (MEL color code 15; approximately 1.0 cm [1.14º] in diameter) presented in the center of one of the boxes for each task. This method, in which the possible stimulus locations were marked with boxes, was used so that it would be similar to that used in our earlier study of two-choice tasks, which showed evidence consistent with the emergent perceptual-feature hypothesis (Vu & Proctor, 2006).

On each trial, the fixation cross and placeholder boxes were presented for 500 msec, after which S1 appeared. After an SOA of 50, 150, 400, or 1,000 msec, S2 was presented. Both S1 and S2 remained on the screen until both R1 and R2 were made, at which time the whole screen went blank. The intertrial interval was 1 sec. Responses were made on a QWERTY keyboard. Responses for Task 1 were made with the left ring finger on the "z" key, the left middle finger on the "x" key, and the left index finger on the "c" key. Responses for Task 2 were made with the right index finger on the ","

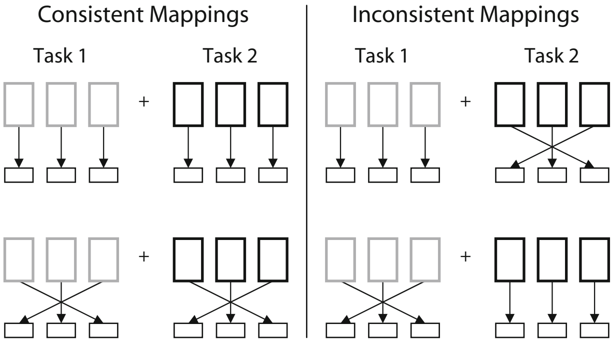

Figure 2. The consistent mapping conditions (left panel) and inconsistent mapping conditions (right panel) for the three-choice tasks.

key, the right middle finger on the "." key, and the right ring finger on the "/" key.

Procedure

The subjects were tested in a single session. In separate blocks, they performed all four Task 1–Task 2 mapping conditions (corresponding–corresponding, corresponding–mirrored, mirrored–corresponding, mirrored–mirrored; see Figure 2). For the consistent conditions, the subjects were instructed to respond with the same mapping for both tasks. They were told that S1 could appear in one of the three leftmost (green) boxes, and they were to respond with their left hand; S2 could appear in one of the three rightmost (red) boxes, and they were to respond with their right hand. The subjects were instructed to perform Task 1 without waiting for S2. For the inconsistent mapping conditions, the subjects were told to perform Task 1 with a corresponding mapping and Task 2 with a mirrored mapping, or vice versa. The order of the conditions was counterbalanced across subjects using a 4 (sequences) × 4 (Task 1–Task 2 mapping conditions) Latin square design.

For each condition, a practice block of 16 trials, for which the subjects were given feedback regarding their accuracy on both tasks after each trial, preceded the experimental block. This block consisted of 180 trials, with no accuracy feedback, with 60 of the stimuli for each task occurring in each of the three stimulus positions in a random order. The pairing of a stimulus for one task with each of the three stimuli for the other task was randomized such that there was an average of 20 trials for each S1–S2 combination. The subjects were told to respond as quickly and accurately as possible. RTs were measured from stimulus onset for the appropriate task to the depression of a response key. The experimenter remained in the room for the entire experiment.

Table 1
Mean Percentage Error for Tasks 1 and 2 As a Function of Task 1–Task 2 Mapping and Stimulus Onset Asynchrony (SOA) for the Side and Middle Positions

Task 1–Task 2 Mapping	SOA (msec) 50	150	400	1,000
Task 1				
Corresponding–corresponding				
Side	0.42	0.83	0.42	0.21
Middle	0.00	0.00	0.00	0.00
Corresponding–mirrored				
Side	3.75	4.79	4.17	3.75
Middle	0.00	0.42	0.00	0.00
Mirrored–corresponding				
Side	0.63	1.04	1.46	2.08
Middle	0.83	0.42	0.00	0.00
Mirrored–mirrored				
Side	0.42	0.63	1.25	0.83
Middle	0.00	0.00	0.00	0.42
Task 2				
Corresponding–corresponding				
Side	1.88	1.25	1.46	1.25
Middle	5.42	2.92	0.42	0.00
Corresponding–mirrored				
Side	2.92	3.55	2.71	2.71
Middle	1.25	0.42	0.42	0.42
Mirrored–corresponding				
Side	4.58	3.75	5.00	6.04
Middle	0.42	0.83	0.42	0.00
Mirrored–mirrored				
Side	1.67	4.58	1.46	1.67
Middle	5.00	3.75	2.50	0.42

RESULTS

Trials with RTs <200 msec or >4,000 msec for either task (<1%) were omitted as outliers. Mean RT and percentage error (PE) for each task were computed for each subject for the side left/right fingers and the middle finger. These data were submitted to 2 (position: side or middle) × 2 (Task 1 mapping: corresponding or mirrored) × 2 (Task 2 mapping: corresponding or mirrored) × 4 (SOA: 50, 150, 400, 1,000 msec) ANOVAs, with all variables being within-subjects. The mean RT data are shown in Figures 3A–3D and the mean PE data in Table 1.

Reaction Time and Percent Error Analyses

For both Task 1 and Task 2, RTs were shorter and PEs slower for the middle position than for the side positions (differences of 85 msec for RT1 and 1.54% for PE1 and of 61 msec for RT2 and 1.36% for PE2) [Fs(1,15) ≥ 12.25, ps ≤ .003]. Thus, the middle-position responses benefited from being corresponding for all Task 1 and Task 2 mapping combinations.

Task 1. There were main effects on RT1 for Task 1 mapping [$F(1,15) = 15.82$, $MS_e = 75{,}204$, $p < .001$] and for Task 2 mapping [$F(1,15) = 18.95$, $MS_e = 35{,}436$, $p < .001$]. RT1 was shorter when the mapping was corresponding (Ms = 739 and 751 msec for Task 1 and Task 2 mappings, respectively) than when it was mirrored (Ms = 835 and 823 msec, respectively). More important, Task 1 mapping interacted with Task 2 mapping [$F(1,15) = 9.92$, $MS_e = 157{,}742$, $p = .007$], showing a mapping consistency benefit: RT1 was shorter when the task mappings were consistent ($M = 732$ msec) than when they were inconsistent ($M = 842$ msec).

Position entered into two-way interactions with Task 1 mapping [$F(1,15) = 4.47$, $MS_e = 9{,}932$, $p = .05$] and Task 2 mapping [$F(1,15) = 9.55$, $MS_e = 4{,}918$, $p = .007$], as well as a three-way interaction with both mapping variables [$F(1,15) = 79.73$, $MS_e = 5{,}717$, $p < .001$]. The latter interaction is of most importance, because it indicates that the consistency effect was different for the middle and side positions. Separate analyses showed that the interaction of Task 1 mapping with Task 2 mapping was significant for the side positions (see Figure 3A) [$F(1,15) = 24.09$, $p < .001$] but not for the middle position [$F(1,15) = 1.91$, $p = .19$]. For the side positions, RT1 was shorter when the task mappings were consistent ($M = 745$ msec) than when they were inconsistent ($M = 915$ msec), replicating Duncan's (1979) finding. Not only did the corresponding–corresponding condition show an advantage over the inconsistent conditions, but so did the mirrored–mirrored condition [Fs(1,15) = 5.77 and 4.59, ps < .05, for comparisons with the corresponding–mirrored and mirrored–corresponding conditions, respectively]. Although the two-way interaction was not significant for the middle position, the difference between the corresponding–corresponding condition and the corresponding–mirrored condition was significant [$F(1,15) = 5.76$, $p = .03$], indicating that there was a consistency benefit for the corresponding mapping (see Figure 3B). This outcome is in agreement with the

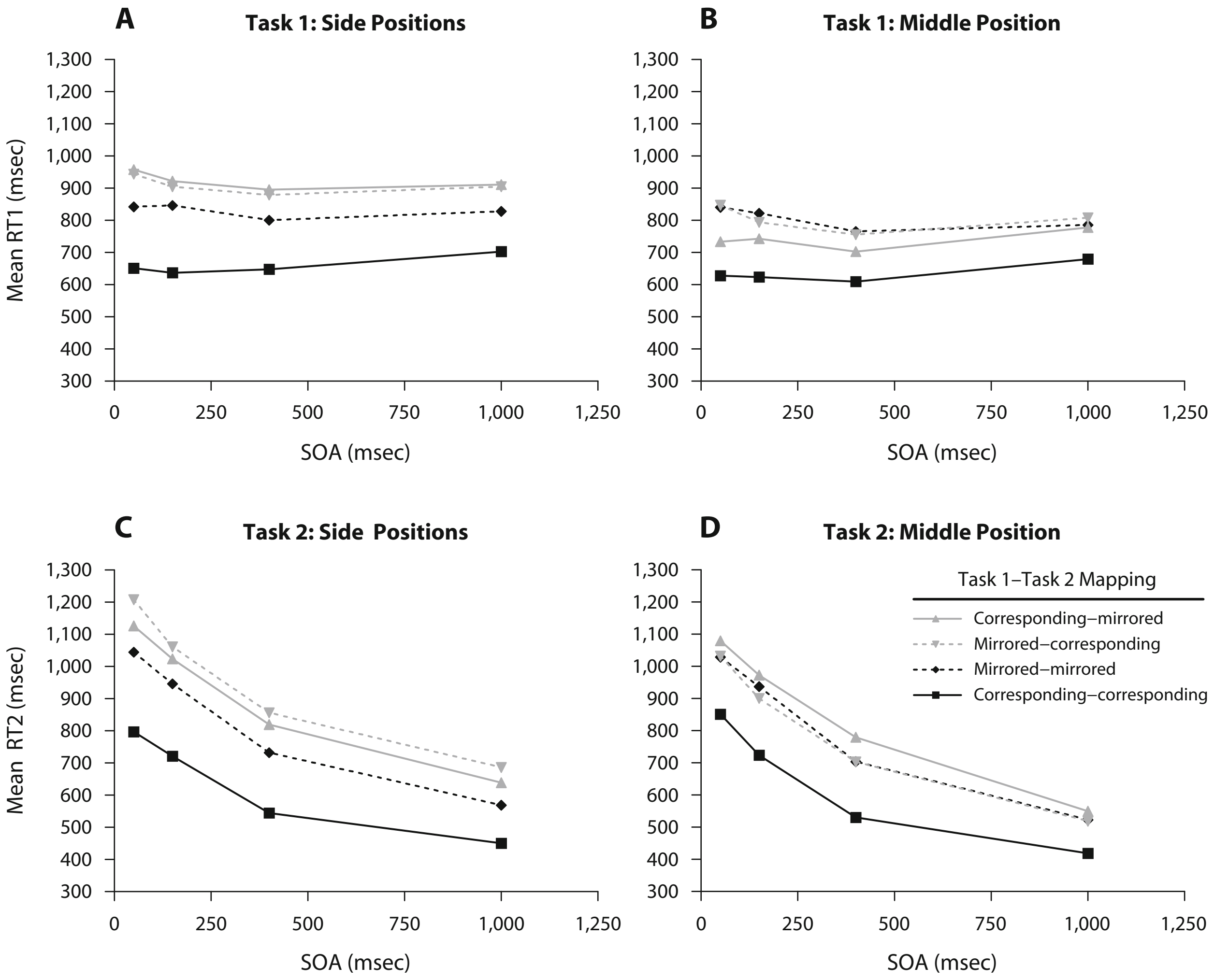

Figure 3. Mean reaction times for Task 1 (RT1; A and B) and for Task 2 (RT2; C and D) as a function of Task 1–Task 2 mapping and stimulus onset asynchrony (SOA) for the side positions (A and C) and middle positions (B and D).

hypothesis that a consistent corresponding mapping can be treated as a single task mapping.

Neither the main effect of SOA nor its interaction with position showed an F ratio greater than 1.0 for RT1. The flat SOA functions for RT1 indicate that the subjects followed the instructions to respond to S1 without waiting for S2 (see, e.g., Pashler & Johnston, 1989, Experiment 1). Thus, there was no evidence that the subjects grouped R1 with R2.

SOA entered into a two-way interaction with Task 1 mapping [$F(3,45) = 5.30$, $MS_e = 23,575$, $p < .003$]: Bonferroni tests showed that the Task 1 mapping effect was significantly larger at the shortest SOA than at the longest SOA ($p = .019$), with the values for the two intermediate SOAS not differing significantly from either one (SRC effects of 125, 111, 86, and 63 msec for the four SOA values, respectively). This was the only effect involving SOA to attain the .05 level. Note that the lack of a significant three-way interaction of the two task mappings with SOA ($F < 1.0$) or four-way interaction of those variables with position [$F(3,45) = 2.72$, $MS_e = 2,440$, $p = .062$] indicates that the consistency benefits for RT1 were not affected significantly by SOA. Although the four-way interaction approached significance, the three-way interaction of the task mappings with SOA was not significant for the middle or side positions alone (ps $\geq .095$). Moreover, the critical comparison with the consistent mirrored mapping condition to the inconsistent conditions for the side positions shows no sign of an interaction [$F(6,90) < 1.$]. This relative lack of influence of SOA is in agreement with the prediction of the emergent mapping-choice account.

For PE1 (see Table 1), the interaction of Task 1 mapping and Task 2 mapping was significant [$F(1,15) = 6.03$, $MS_e = 26.62$, $p = .027$], as was the three-way interaction of those variables with position [$F(1,15) = 4.99$, $MS_e = 23.84$, $p = .041$]. In agreement with the RT1 data, PE1 was less when the task mappings were consistent ($M =$ 0.34%) than when they were inconsistent ($M = 1.46\%$). This pattern was significant only for the side positions [$F(1,15) = 5.60$, $MS_e = 49.63$, $p = .032$], for which the corresponding–mirrored mapping showed a particularly high error rate ($M = 4.12\%$).

Task 2. The main effects on RT2 of Task 1 mapping [$F(1,15) = 11.78$, $MS_e = 85{,}964$, $p = .004$] and of Task 2 mapping [$F(1,15) = 27.70$, $MS_e = 39{,}084$, $p < .001$] were significant. For both task mappings, RT2 was shorter when the mapping was corresponding (*M*s = 752 and 750 msec) than when it was mirrored (*M*s = 841 and 842 msec). As for RT1, Task 1 mapping interacted with Task 2 mapping for RT2 [$F(1,15) = 25.17$, $MS_e = 117{,}797$, $p < .001$], indicating a consistency benefit: RT2 was shorter when the mappings were consistent ($M = 720$ msec) than when they were not ($M = 873$ msec). Position interacted with Task 1 mapping [$F(1,15) = 19.65$, $MS_e = 146{,}503$, $p < .001$] and Task 2 mapping [$F(1,15) = 9.92$, $MS_e = 51{,}636$, $p = .007$], and with both mapping variables in a three-way interaction [$F(1,15) = 45.19$, $MS_e = 6{,}965$, $p < .001$].

The latter interaction is again of most interest because it indicates that the consistency effect was different for the side and middle positions. Follow-up analyses showed that Task 1 mapping interacted with Task 2 mapping both for the side positions [$F(1,15) = 32.27$, $p < .001$] and for the middle position [$F(1,15) = 15.32$, $p < .001$]. For the side positions (see Figure 3C), RT2 was shorter when the mappings were consistent ($M = 726$ msec) than when they were not ($M = 928$ msec). For the middle position (see Figure 3D), Bonferroni pairwise comparisons showed that RT2 was shorter when both the Task 1 and the Task 2 mappings were corresponding ($M = 631$ msec) than when both were mirrored ($M = 798$ msec), when only the Task 2 mapping was corresponding ($M = 789$ msec), or when only the Task 2 mapping was mirrored ($M = 846$ msec); these latter three conditions did not differ significantly. This analysis of middle-position responses again indicates a benefit for consistent correspondence across the two tasks, although the middle stimulus and response were identical for all mapping combinations.

The main effect of SOA was significant [$F(3,45) = 198.80$, $MS_e = 28{,}907$, $p < .001$]: RT2 showed a typical PRP effect (e.g., Pashler, 1994), which is that RT2 increased as SOA decreased (*M*s = 1,021, 911, 709, and 544 msec for the four SOAs, respectively). SOA interacted with Task 1 mapping [$F(3,45) = 4.17$, $MS_e = 146{,}503$, $p < .011$] and Task 2 mapping [$F(3,45) = 5.81$, $MS_e = 51.636$, $p = .005$] separately, as well as in combination [$F(3,45) = 5.77$, $MS_e = 6{,}965$, $p = .002$]. None of these terms entered into higher order interactions with position, showing that the same general pattern held across side and middle positions. The interaction of SOA with the two mappings indicates that as SOA increased, RT2 decreased less for the corresponding–corresponding condition than for the other conditions (see Figures 3C and 3D). This pattern was supported by a separate ANOVA performed on the other three conditions, which showed no overall differences among conditions [$F(2,30) = 1.86$, $p = .17$] and no interaction with SOA ($F < 1$). Thus, this last analysis shows that the benefit for the crucial mirrored–mirrored condition relative to the mirrored–corresponding and corresponding–mirrored conditions was unaffected by SOA. This result again provides evidence in agreement with the emergent mapping-choice account.

For PE2, there were main effects of Task 1 mapping [$F(1,15) = 6.12$, $MS_e = 14.06$, $p = .026$] and of SOA [$F(3,45) = 4.68$, $MS_e = 11.21$, $p = .006$]. PE2 was less when Task 1 mapping was corresponding ($M = 1.81\%$) than when it was mirrored ($M = 2.63\%$), and it decreased as SOA increased (*M*s = 2.9%, 2.6%, 1.8%, and 1.6% at the four SOAs). Position interacted with SOA [$F(1,15) = 6.92$, $MS_e = 7.06$, $p = .001$]: PE did not vary systematically as a function of SOA for the side positions (*M*s = 2.7%, 3.3%, 2.7%, and 2.9%), whereas it decreased as SOA increased for the middle position (*M*s = 3.0%, 2.0%, 0.9%, and 0.2%).

Task 1 mapping did not interact with Task 2 mapping, but the three-way interaction of those variables with position was significant [$F(1,15) = 28.39$, $MS_e = 18.37$, $p < .001$]. Additional analyses showed that the two mappings interacted for the side positions [$F(1,15) = 26.18$, $p < .001$] and for the middle position [$F(1,15) = 19.29$, $p = .001$], but in different manners. For the side positions, PE2 was lower when the mappings were consistent ($M = 1.90\%$) than when they were not ($M = 3.91\%$), with the mirrored–corresponding condition showing a particularly high error rate ($M = 4.84\%$). For the middle position, the error rate was lower when the task mappings were inconsistent ($M = 0.53\%$) than when they were consistent ($M = 2.56\%$). In the overall ANOVA, the Task 1 and Task 2 mappings also entered into a three-way interaction with SOA [$F(3,45) = 4.27$, $MS_e = 12.47$, $p = .016$]. There was a cost for consistent mappings relative to inconsistent mappings at the two short SOAs ($M = 1.09\%$) that changed to a benefit at the two longer SOAs ($M = 1.06\%$).

Error Types

For the two side stimulus positions, an incorrect response could be the adjacent middle position or the position opposite the correct response (which would be correct in the inconsistent mapping conditions if the alternative mapping rule were applied). The total number of errors of each type across all subjects was obtained for each Task 1–Task 2 mapping condition, collapsed across SOA. Analyses of the errors for the side positions showed that there was a significant difference in the error types across the four conditions for both Task 1 and Task 2 [Task 1, $\chi^2(3) = 12.05$, $p = .007$; Task 2, $\chi^2(3) = 46.31$, $p < .001$]. For the corresponding–corresponding condition, the total number of errors was low (9 for Task 1 and 28 for Task 2), and there was no significant difference in error types between tasks; for the mirrored–mirrored condition, more alternative-rule errors (i.e., making the corresponding response) were committed than adjacent errors [Task 1, 13 vs. 2, $\chi^2(1) = 8.07$, $p = .005$; Task 2, 35 vs. 10, $\chi^2(1) = 13.89$, $p < .001$]. More errors were made in the inconsistent mapping conditions, with both showing large differences in favor of the alternative-rule error type [Task 1, 76 vs. 3 for corresponding–mirrored, 24 vs. 1 for mirrored–corresponding, $\chi^2(1) = 21.16$, $p < .001$; Task 2, 54 vs. 3 for corresponding–mirrored, 81 vs. 12 for mirrored–corresponding, $\chi^2(1) = 45.63, p < .001$]. Thus, for both tasks, when the mappings were inconsistent, errors for the side-position stimuli were predominantly the response that would have been correct if the alternative mapping rule were in effect for that task, with the strongest tendency being to make the opposite response when the task mapping was corresponding.

For the middle position, an incorrect response was always adjacent, to the right or left of the correct location. Few errors were made for either task regardless of whether the mappings were consistent or inconsistent, and these errors did not differ between left and right positions. This lack of tendency to make one or the other type of incorrect response is to be expected, because both task mappings require the middle response to be made to a middle stimulus.

GENERAL DISCUSSION

The results of the present experiment for the side positions replicated Duncan's (1979) findings. For both Task 1 and Task 2, performance was better when the mappings were consistent than when they were not. This effect was evident not only for the corresponding–corresponding condition but also for the mirrored–mirrored condition, although there was also a substantial advantage for the former condition relative to the latter. For the mirrored–mirrored condition, the consistency benefit was sufficiently large that RTs for a task were shorter with a mirrored mapping than with a corresponding mapping when the mapping for the paired task was also mirrored. For the 400-msec SOA, most similar to the longest (450-msec) SOA in Duncan's (1979) study, there was little indication of the benefit for the consistent mirrored mapping being reduced relative to the shortest (50-msec) SOA.

Extending the SOA to 1,000 msec also had little impact on the consistency benefit for the side positions. Overall, mapping consistency interacted significantly with SOA for RT2 but not for RT1. However, this interaction was not evident in the PE data and reflected a pattern in RT1 and RT2 for the corresponding–corresponding condition RTs to approach those of the mirrored–mirrored condition and the inconsistent conditions as SOA increased. The consistency benefit was still evident at the 1,000-msec SOA, and more important, there was no reduction of the benefit for having two mirrored mappings relative to having different mappings for the two tasks. This finding, which is similar to that for pairs of four-choice tasks (Proctor & Vu, 2009), implicates different processes as responsible for the benefit of consistent mirrored mappings for three- and four-choice tasks (an emergent mapping choice) than for two-choice tasks (selection based on an emergent perceptual blank feature).

It is possible that the consistency benefit for the mirrored–mirrored condition would be eliminated in three-choice tasks, as it is in two-choice tasks, if the SOA were increased beyond 1,000 msec. We think that this is unlikely, because the benefit showed little tendency to decrease at the 1,000-msec SOA, whereas it was eliminated at that SOA for pairs of two-choice tasks (Vu & Proctor, 2006). Thus, the evidence does not suggest that the different result patterns for three- and two-choice tasks are due just to the responses being easier to prepare in two-choice tasks. It is also possible that if boxes were not used as placeholders, so that the blank areas were truly blank, the results would conform to the emergent perceptual-feature account. However, this possibility is also unlikely, because the decrease in consistency benefit with SOA for two-choice tasks has been obtained both with placeholders (Vu & Proctor, 2006) and without (Ivry et al., 1998), and the results of the present three-choice tasks with placeholders closely replicated those of Duncan (1979), obtained without placeholders. Instead, the difference seems to be that with two-choice tasks, a strategy of responding compatibly to the blank regions is used that is not used with three-choice tasks.

The conclusion that two-choice tasks allow a strategy to be adopted that three- and four-choice tasks do not is in agreement with the view that the difference in processing between two-choice tasks and tasks with more than two alternatives is more than just a difference in amount (Shaffer, 1967; Wühr & Kunde, 2008). When only a single noncorresponding response alternative for each stimulus location exists, strategies can be adopted for individual tasks that allow preparation of noncorresponding responses that are cued in advance and for dual tasks that allow emergent perceptual properties to be utilized. These strategies are difficult or impossible to implement for three- and four-choice tasks in which, respectively, two and three response alternatives do not correspond with a given stimulus location.

A second contribution of the present study is the analysis of the data for middle-position responses, because they afford evaluation of whether mapping consistency produces any benefit when the exact same stimulus and response are involved in the consistent and inconsistent mapping combinations. The middle-position responses showed a consistency benefit when both task mappings were corresponding but not when both were mirrored. The absence of a benefit at the middle position with the consistent mirrored mappings over the inconsistent mappings indicates that consistency at the level of the global mirrored mapping is not sufficient to make a difference when there is consistency at the level of the individual S–R pairing. This result suggests that, when one task mapping is mirrored and the other corresponding, a choice between mapping rules is not made prior to determination of stimulus position. Any such choice appears to be made only if the stimulus is identified as being in a side position, for which different responses are required when the mapping is corresponding for one task and mirrored for the other.

Within a sequential process account of the type proposed by Duncan (1979), the result pattern could be interpreted as suggesting that subjects first determine whether the stimulus is in a middle or side position. If the position is the middle, they execute the corresponding response; if

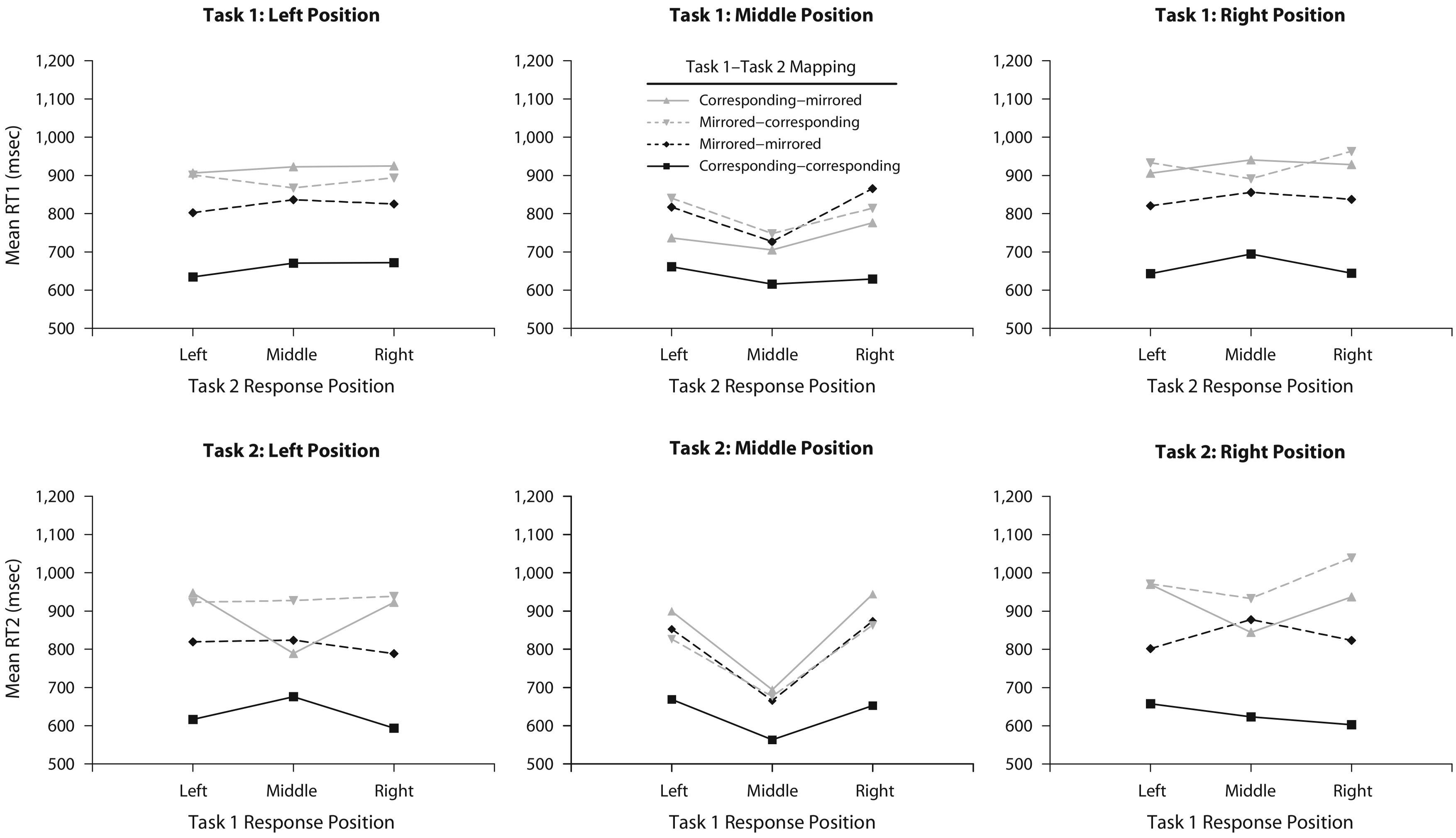

Figure 4. Mean reaction times for Task 1 (RT1; top panels) and for Task 2 (RT2; bottom panels) in milliseconds for the left, middle, and right positions as a function of the position of the other task's response and Task 1–Task 2 mapping.

the position is a side, processing proceeds with the choice of a corresponding or a mirrored mapping rule, followed by its application. This explanation is supported by R–R compatibility analyses, not reported in the Results section, which show that performance at the middle position for one task benefited from the response for the other task also being at the middle position, whereas performance at the side positions benefited from the response for the other task being in either of the side positions and not just the same position (see Figure 4 for means). Thus, although there is little evidence that responses are selected on the basis of the emergent perceptual blank feature when both stimuli are in side positions, distinguishing whether stimuli are in middle or side positions seems to be part of the response-selection process. Given that the subjects make a categorization that would be necessary for use of the emergent blank feature strategy, there are several possible reasons that they may not be using it. A likely possibility is that the process of determining the locations of S1 and S2 itself focuses attention on the stimuli in those locations.

The large benefit for the corresponding–corresponding condition even at the middle positions indicates a second component to the consistency benefit that is a consequence of knowing that the corresponding response is correct on all trials for both tasks. This facilitatory component for the corresponding–corresponding condition is like that found for pure compatible mappings within a single task compared with mixed mappings for which some S–R relations are compatible and others incompatible (e.g., Duncan, 1977; Shaffer, 1965; Vu & Proctor, 2004). The benefit for completely corresponding responses on all trials is often attributed to subjects' being able to respond on the basis of automatic activation produced by long-term S–R associations (e.g., Proctor & Vu, 2002). Evidence that the advantage for the corresponding–corresponding condition over the mirrored–mirrored condition has a similar basis comes from the finding that the advantage was of comparable magnitude regardless of whether responding was to the middle position or to one of the side positions (middle position, $M = 168$ msec for RT1 and $M = 168$ msec for RT2; side positions, $M = 169$ msec for RT1 and $M = 195$ msec for RT2). This facilitatory component operates in two-, three-, and four-choice tasks, as is indicated by the fact that in all of them, the consistent corresponding mappings show an advantage over the consistent mirrored mappings.

To conclude, Duncan (1979) proposed that "Performance decrements may often result from failure (or limits) of new or *emergent* processes whose existence depends on the particular *set* of tasks combined" (p. 216). He provided evidence for an emergent mapping choice for pairs of three-choice tasks that must be made when the stimulus–response mappings for the two tasks differ. By extending the SOA between S1 and S2 to 1,000 msec and finding no reduction of the benefit for consistent mirrored mappings, we have provided stronger evidence consistent with a critical prediction of the emergent mapping-choice account, that the consistency benefit should be evident even when the SOA is long. This relative independence from SOA is not apparent for pairs of two-choice tasks (Ivry et al., 1998; Vu & Proctor, 2006), for which results suggest a different primary factor contributing to the benefit for consistent mirrored mappings: an emergent perceptual feature, which allows subjects to adopt a strategy of responding compatibly to the unfilled boxes at short SOAs. In the present study, we also provided evidence suggesting that stimulus positions are categorized first as middle or side, with mapping choice being a factor only if the mappings yield conflicting responses for the identified location subset (i.e., for the side locations). Finally, we showed that the consistency benefit when both tasks use pure corresponding mappings includes a component that extends to the middle positions. This component, which causes the consistency benefit to be larger for corresponding mappings than for mirrored mappings, is a consequence of the subjects' being able to adopt a task set that allows the most natural, corresponding response to be made to any stimulus that occurs. Across all studies, the mapping consistency results support Duncan's (1979) general message: "A divided attention situation is more than the sum of its component single tasks. *Emergent* aspects of the whole situation must also be considered" (p. 216).

AUTHOR NOTE

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